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Maritimes Region
Canadian Science Advisory Secretariat
Science Advisory Report 2015/034

ASSESSMENT OF NOVA SCOTIA (4VWX) SNOW CRAB

Snow crab

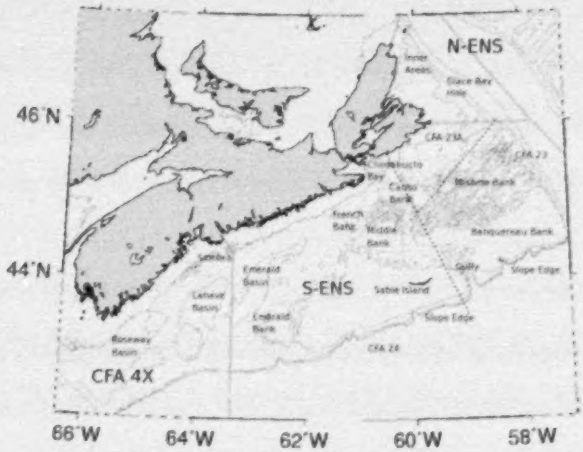


Figure 1. Map of the Scotian Shelf and Crab Fishing Areas (CFAs).

Context

Snow Crab have been a dominant macro-invertebrate in the Scotian Shelf Ecosystem (SSE) since the decline of the groundfish. They are observed in large numbers in deep, soft-bottom substrates ranging from 60 to 280 m and at temperatures generally less than 6°C. The SSE Snow Crab are in the southern-most extreme of their spatial distribution in the Northwest Atlantic.

The fishery has been in existence since the early 1970s in Nova Scotia. The management of the Snow Crab fisheries in the SSE was initially based on effort controls (season, license, trap limits) from 1982 to 1993 with harvesting during June-November of hard-shelled males larger than 95 mm carapace width (CW). Additional management measures were introduced from 1994 to 1999: IBQs (individual boat quotas), TACs (total allowable catches), 100% dockside monitoring, mandatory logbooks and at-sea monitoring by certified observers. In 2005, many Crab Fishing Areas (CFAs) and subareas were merged with the resulting divisions being N-ENS (North-Eastern Nova Scotia, formerly CFAs 20-22), S-ENS (South-Eastern Nova Scotia, CFAs 23, 24), and 4X (Figure 1).

In support of the fishery, DFO Maritimes Fisheries and Aquaculture Management requests from DFO Science an annual assessment of resource status. This document is a scientific overview of the assessment. An assessment of the status of 4VWX Snow Crab is based on fishery independent surveys using indicators of abundance, reproductive potential, recruitment, and exploitation rates. Commercial catch rates and other fishery statistics are reported. Harvest advice for the next year is provided.

This Science Advisory Report is from the February 24, 2015, Assessment of Nova Scotia (4VWX) Snow Crab. Additional publications from this process will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Landings in 2014 for N-ENS and S-ENS were 778 and 11,267 t, respectively, and they were 79 t in 4X for the 2013/2014 season, representing similar landings to the previous year in S-ENS and N-ENS and 33% decrease in 4X relative to the previous year. Total Allowable Catches (TACs) in 2014 were 783 t, 11,311 t and 80 t in N-ENS, S-ENS and 4X, respectively.
- Non-standardized catch rates in 2014 decreased by 2% in N-ENS and increased by 8% in S-ENS and 25% in 4X, relative to the previous year.
- In N-ENS, the estimated soft shell crab discard rate (% of total landings) was 3.2% in 2014, consistent with 3.4% in 2013. This is substantially lower than previous levels (111% in 2007), due to an increase in spring fishing and an ageing fishable stock. In S-ENS, 2014 estimated soft shell discards were 1.9% of landings, relative to 1.7% in 2013. The shift towards earlier fishing seasons has improved soft shell crab handling rates in both N-ENS and S-ENS though continued diligence is important to protect incoming recruitment. Soft shell discards in 4X are negligible, in large part due to a fall / winter fishery.
- The post-fishery fishable biomass decreased by 40% (2,075 t relative to 3,451 t in 2013) in N-ENS and by 13% (40,119 t relative to 46,203 t in 2013) in S-ENS. In 4X, the biomass estimate increased by 388% (2059 t relative to 531 t in 2013), based on only a subset of stations completed in 2014. The results in 4X should be considered preliminary, pending further analysis of survey and commercial fishing data. In all areas, results were more uncertain in 2014 compared to previous years due to changes in survey timing, survey duration and vessel. An additional uncertainty exists in N-ENS, surrounding migration into the area which is not detected during trawl surveys, which may affect the biomass available during the fishery.
- Based on size-frequency histograms of the male snow crab population, very limited internal recruitment to the fishery is expected in N-ENS and 4X. S-ENS internal recruitment is expected to remain at moderate levels. Migration of crab from outside a given area can serve as recruitment to its fishery though is unreliable based on its apparent episodic nature.
- Mature female Snow Crab abundance has continued to decline in N-ENS and S- ENS and assumed associated egg production continues to decline after reaching highs in 2007/2008. Sex ratios (proportion female) continue to be male-dominated in N-ENS (though slightly higher than 2013), are stabilizing at low levels in S-ENS and declined from more moderate levels in 4X. There was a strong pulse of immature crab observed in the 2014 survey in all areas, which may provide increased production in the future. Newly mature female crab are expected in the next 1-3 years in N-ENS and S-ENS. In 4X there is more uncertainty surrounding short term expectations of egg production.
- Estimated fishing mortality rates for 2014 were 0.30, 0.18 and 0.08 for N-ENS, S-ENS and 4X, respectively.
- Average bottom temperatures in 2014 were slightly warmer in N-ENS and S-ENS compared to 2013, which continues a general warming trend observed since the early-1990s. The bottom temperatures decreased in 4X in each of the past two years after the extreme warm water event of 2012 though still remain above the long-term mean for the area. Changing temperatures will have an impact on available Snow Crab habitat into the future.
- Atlantic Halibut, Atlantic Wolfish and skate species appear to be the predominant predators of snow crab on the Scotian Shelf though snow crab does not appear to be an important part of their diet (2.2%). Population trends from these species are uncertain though increased predation is

likely to lower future recruitment to the fishable biomass and affect movement patterns of Snow Crab.

- Bycatch levels are extremely low in this fishery. In N-ENS and S-ENS, combined estimates of bycatch were 0.01% of Snow Crab landings. 4X shows higher (relative to ENS) bycatch rates at 2.2 % of Snow Crab landings.
- The potential impacts of seismic activity on Snow Crab productivity are unknown but anecdotal evidence suggests it may be detrimental to recruitment and migrations. Unreported or misreported landings may further increase uncertainty in the stock assessment results. Anecdotal evidence from commercial fishers suggest unreported landings may be occurring in S-ENS.
- A reference points-based Precautionary approach (PA) has been implemented in this fishery. The Limit reference point (LRP) is 25% of carrying capacity and the Upper stock reference (USR) is 50% of carrying capacity. The Target Removal reference is 20% of the fishable biomass (FB) in each area and the Removal reference is not to exceed FMSY. Various secondary (population and ecosystem) indicators are taken into consideration for management decisions.
- In N-ENS, fishable biomass has declined over the past three years, although the stock remains in the "healthy" zone (FB > USR), it is getting close to the "cautious" zone. A gap in the length frequency histogram suggests limited local recruitment in the medium to long-term. Based on the biomass trends obtained during the survey a decreased TAC is recommended.
- S-ENS fishable biomass is considered to be in the "healthy" zone (FB > USR). Despite the decrease in fishable biomass it continues to be high relative to historic levels and with recruitment expected for at least the next three to four years, there remains scope for flexibility. A status-quo to marginal decrease in TAC is recommended.
- In 4X, fishable biomass has moved from the "cautious" zone (LSR < FB < USR) into the "healthy" zone (USR < FB); however there is uncertainty in this biomass estimate as the westernmost portion of the survey stations in 4X were not completed. In addition, recruitment into next season is uncertain leading to the recommendation of a continued conservative harvest strategy pending further analysis prior to the 2015-2016 season.

BACKGROUND

Species Biology

Snow Crab (Chionoecetes *opilio*, O. Fabricius) is a subarctic species with a distribution from northern Labrador to near the Gulf of Maine. Habitat preference is for soft mud bottoms. Smaller crabs are found in more complex habitats with shelter. Commercial crab (male, >95 mm carapace width; CW) in large numbers are found at depths from 60 to 280 m and temperatures from -1 to 6°C on the Scotian Shelf Ecosystem (SSE). Temperatures greater than 7°C are known to be detrimental to Snow Crab. The primary food items of crab are shrimp, fish (Capelin and Lumpfish), starfish, sea urchins, worms, detritus, large zooplankton, other crabs, Ocean Quahaug, molluscs, sea snails and sea anemones. Predators of Snow Crab are Atlantic Halibut, skates (especially Thorny Skate), Atlantic Cod, seals, American Plaice, squids, and other crabs. Crab in the size range of 3 to 30 mm CW are particularly vulnerable to predation, as are soft-shelled crab in the spring moulting season. Snow Crab have been a dominant macro-invertebrate in the SSE since the decline of the groundfish during the late 1980s and early 1990s. The SSE Snow Crab are in the southern-most extreme of their spatial distribution in the Northwest Atlantic.

Fishery

The Snow Crab fishery in eastern Canada began in 1960 with incidental bycatches by groundfish draggers near Gaspé, Quebec. Its development was slow until the 1980s, when it began expanding rapidly to become one of the largest fisheries in Canada in terms of landings and landed value. On the Scotian Shelf, the fishery has been in existence since the early 1970s. The Scotian Shelf Snow Crab fishery lands only males with carapace width ≥ 95 mm. There is also a concerted effort to avoid areas of newly moulted (soft shelled) crab and to discard immature males. Total landings increased to record-levels of approximately 10,000 t each year in the early 2000s and have surpassed these previous highs since 2009 (Figure 2). In 2005, many Crab Fishing Areas (CFAs) and subareas were merged with the resulting divisions being N-ENS (North-Eastern Nova Scotia, formerly CFAs 20-22), S-ENS (South-Eastern Nova Scotia, CFAs 23, 24), and 4X (Figure 1). Landings in 2014 for N-ENS and S-ENS were 778 and 11,267 t, respectively, and they were 79 t in 4X for the 2013/2014 season, representing similar landings to the previous year in S-ENS and N-ENS and 33% decrease in 4X relative to the previous year (Figures 2). Total Allowable Catches (TACs) in 2014 were 783 t, 11,311 t and 80 t in N-ENS, S-ENS and 4X, respectively (Figure 2, Tables 1-3).

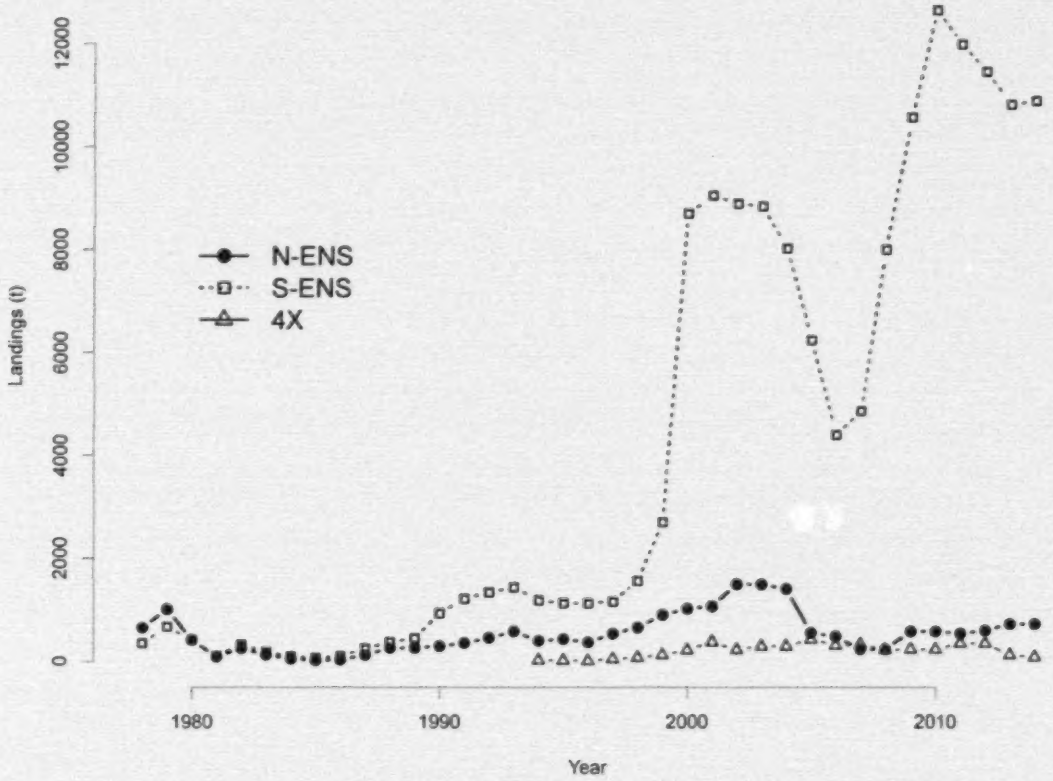


Figure 2. Temporal variations in the landings (t) of Snow Crab on the Scotian Shelf. The landings follow the TACs with little deviation, so the TACs are not shown. For 4X, the year refers to the starting year of the season.

Table 1. Summary of Snow Crab fisheries in N-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
2005	78	566	562	31	18.4
2006	78	487	486	36	13.7
2007	78	244	233	24	9.9
2008	78	244	238	34	7.0
2009	78	576	579	76	7.6
2010	78	576	576	55	10.5
2011	78	534	536	110	4.8
2012	78	603	603	117	5.1
2013	78	783	783	106	7.4
2014	78	783	778	104	7.4

Table 2. Summary of Snow Crab fisheries in S-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
2005	114	6,353	6,407	110	58.5
2006	114	4,510	4,486	91	49.4
2007	115	4,950	4,942	100	49.3
2008	115	8,316	8,253	96	85.9
2009	116	10,800	10,645	90	118.8
2010	116	13,200	13,150	103	128.3
2011	116	12,120	12,135	106	118.8
2012	116	11,707	11,733	98	120
2013	116	11,311	11,309	104	108.7
2014	116	11,311	11,267	112	100.2

Table 3. Summary of Snow Crab fisheries in 4X.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
2005/06	9	337.6	306	29	10.8
2006/07	9	337.6	317	28	11.5
2007/08	9	230	220	18	12.1
2008/09	9	230	229	28	8.0
2009/10	9	230	229	36	6.4
2010/11	9	346	345	38	9.0
2011/12	9	346	344	29	11.8
2012/13	9	263	118	13	9.6
2013/14	9	80	79	15	5.1
2014/15[1]	9	80	59	34	1.7

Note: [1]As of February 10, 2015. Season still in progress.

In 2014, the spatial distribution of landings was focused on mid-shore and offshore areas in S-ENS although additional effort was observed in the near-shore. In N-ENS, effort was focused on the southeast region of the inner gutter and the Glace Bay Hole area in 2014 (Maps 1, 2). There was no effort on the offshore-slope areas of S-ENS in 2014.

Non-standardized catch rates in 2014 were 104 kg/trap haul in N-ENS, 112 kg/trap haul in S-ENS, and 15 kg/trap haul in 4X in 2013/2014 – which relative to the previous year represents a decrease of 2%, an increase of 8% and an increase of 25%, respectively (Tables 1-3, Figure 3, Map 2).

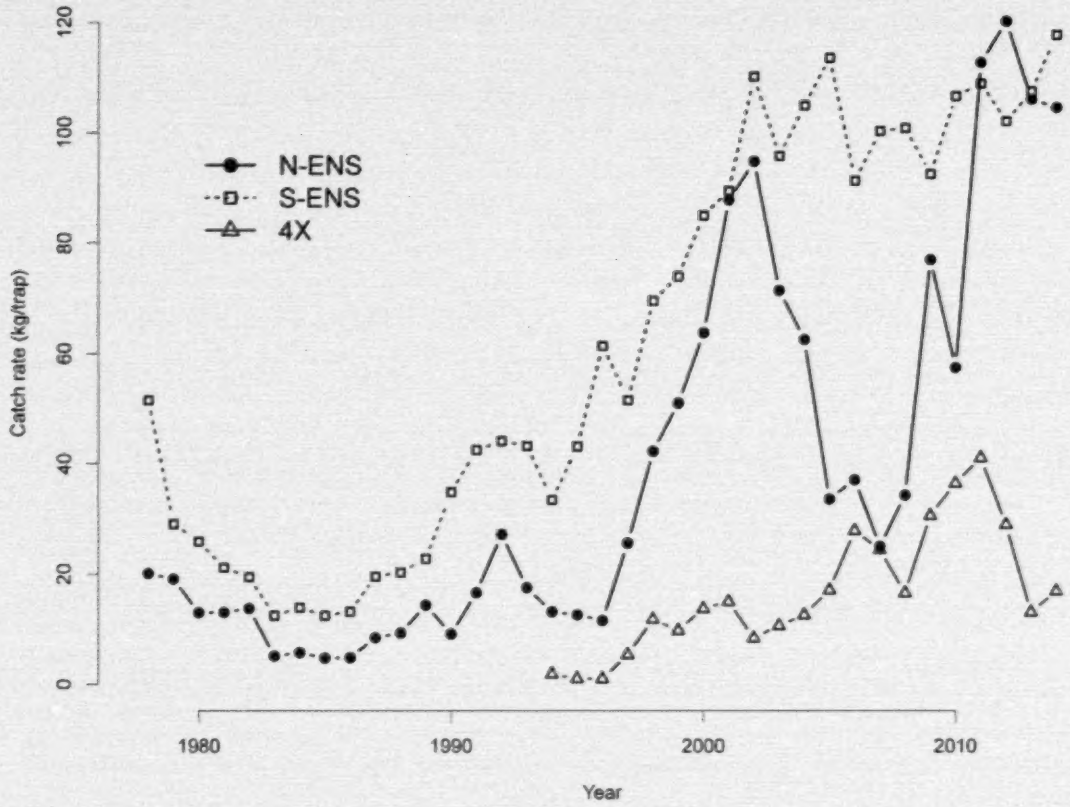


Figure 3. Temporal variations in catch rates of Snow Crab on the Scotian Shelf, expressed as kg/trap haul. Trap design and size have changed over time. No corrections for these varying trap-types nor soak time and bait-type have been made.

Carapace condition (CC) defines the approximate age (since terminal moult) of the terminally moulted crab based on the relative development and subsequent decay of the carapace. CC1 signifies a newly moulted crab, soft shelled, with no epibiont growth. The oldest carapace condition CC5 signifies extensive shell decay where there is no expectation of survival into the next year. In N-ENS, CC1 and CC2 crab collectively represented approximately 19% of the total catch (Figures 4a-c), relative to 6% in 2013. This is still a substantial reduction from 2008 and before, when most (or all) of the landings came from the summer fishing season. The spring season (2008-present) was adopted to reduce fishing intensity in this summer season and also to encourage fishing during the earlier period when newly molted crab are too weak and soft to easily enter into traps. After a successful trial in 2008, the majority of landings (> 65%) from N-ENS were caught during the spring season from 2009 to 2013. Due mostly to spring ice conditions, 2014 spring landings represented only 53% of N-ENS total landings. This resulted in an increased capture of soft shelled animals though the presence of recruiting animals suggests external migration (likely from the Gulf of St. Lawrence) as little to no internal recruitment was expected based on the previous year's trawl survey. There has been a shift towards larger animals in N-ENS catches in the past three years suggesting higher survival of immature crab (lack of handling mortality of soft-shelled crab) and a decreased dependence on newly recruited animals. The increasing mean size of N-ENS has also allowed catch rates (on a kg/trap basis) to remain high when the actual number of crab/trap has fallen steadily since 2011. There were few sub-legal sized crab in N-ENS commercial catches as compared to S-ENS, which may indicate very limited recruitment in future seasons without external immigration. The relative percentage of CC4 crab has decreased in N-ENS in

2014, relative to 2013, which does not reflect the ageing population assumed to currently exist in N-ENS.

In S-ENS, the occurrence of CC1 crab remains at low (approximately 1%) levels. There was an increase in the proportion of CC2 crab from 3.3% in 2013 to 15.9% in 2014. The proportion of CC2 crab in 2014 represented a return to a more typical level observed in the fishery (Figures 4a-c). Hard shell crab dominated the catch with 78% CC3 and 5% CC4. CC5 levels were again negligible in 2014.

In 4X for the 2013/14 season, CC1 and CC2 crab collectively represented approximately 3% of the total catch, slightly higher than 2012/13. The commercial catches are heavily dominated by CC3 and CC4 crab with a combined percent of approximately 97%. The data from 4X are not directly comparable to N-ENS and S-ENS as their fishing season is disjunct from these two management areas. The fall / winter 4X fishery continues to show negligible levels of soft crab.

CC5 crab represented less than 2% of the total observed catch in all areas. The abundance estimates of old male crab (CC5) has been stable in the long-term record and below the detection limit on the Scotian Shelf surveys.

In N-ENS, the estimated soft shell crab discard rate (% of total landings) was 3.2% in 2014, consistent with 3.4% in 2013. This consistent percent of soft crab, coupled with the relative increase in CC2 crab, suggests that the majority of the freshly moulted (CC1 and CC2) crab encountered by the 2014 N-ENS summer fishery had hardened beyond the objective measure (durometer >68) of soft shelled crab. This is substantially lower than previous levels (111% in 2007), due to an increase in spring fishing and an ageing fishable stock. In S-ENS, 2014 estimated soft shell discards were 1.9% of landings, relative to 1.7% in 2013. The shift towards earlier fishing seasons has improved soft shell crab handling rates in both N-ENS and S-ENS though continued diligence is important to protect incoming recruitment. Soft shell discards in 4X are negligible, in large part due to a fall / winter fishery.

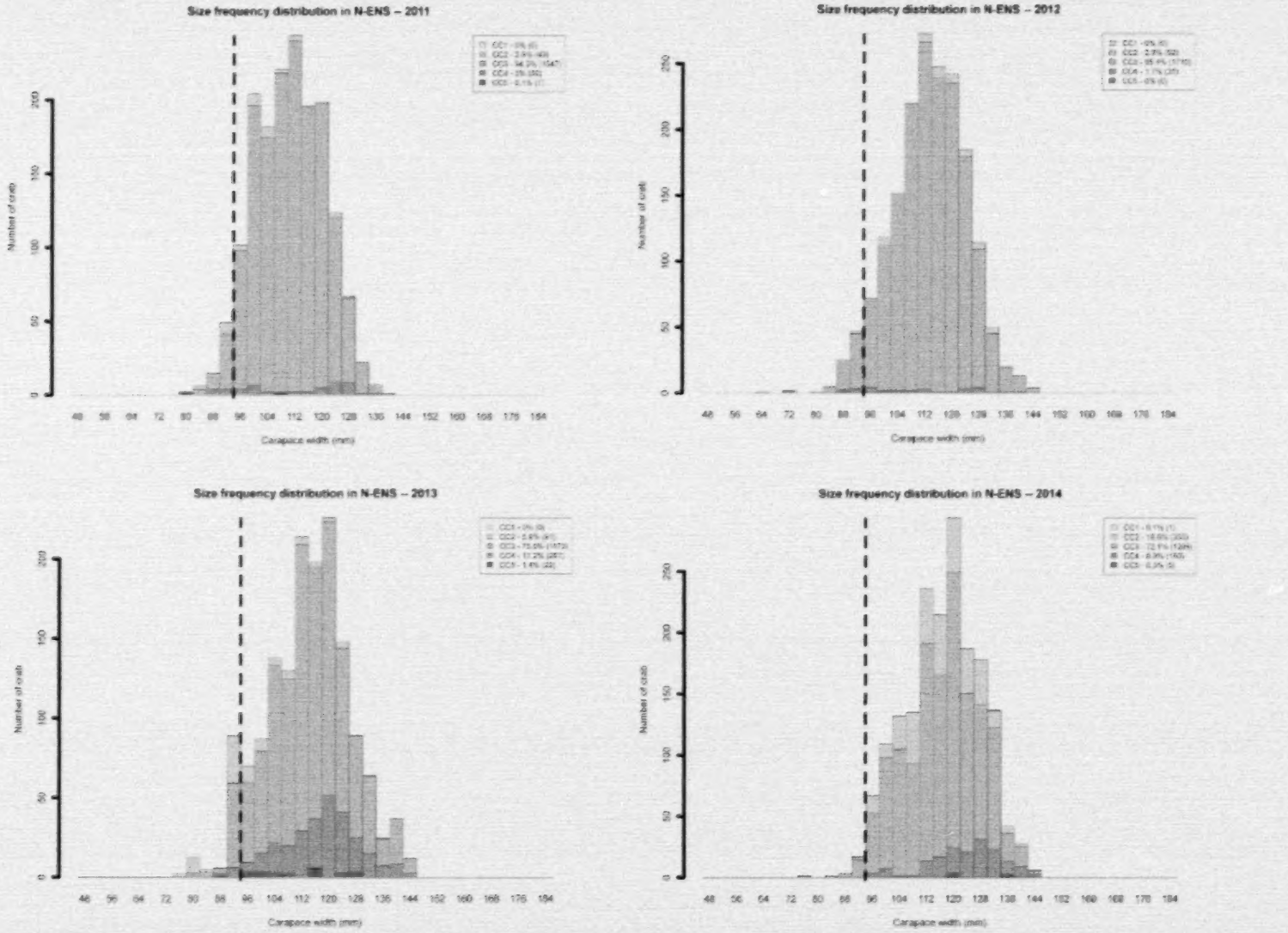

Size frequency distribution in N-ENS – 2011
Size frequency distribution in N-ENS – 2012
Size frequency distribution in N-ENS – 2013
Size frequency distribution in N-ENS – 2014
Number of crab
Carapace width (mm)

Figure 4a. Size frequency distribution of all at-sea observer monitored Snow Crab in N-ENS broken down by carapace condition. Vertical lines indicate 95 mm CW, minimum legal commercial size.

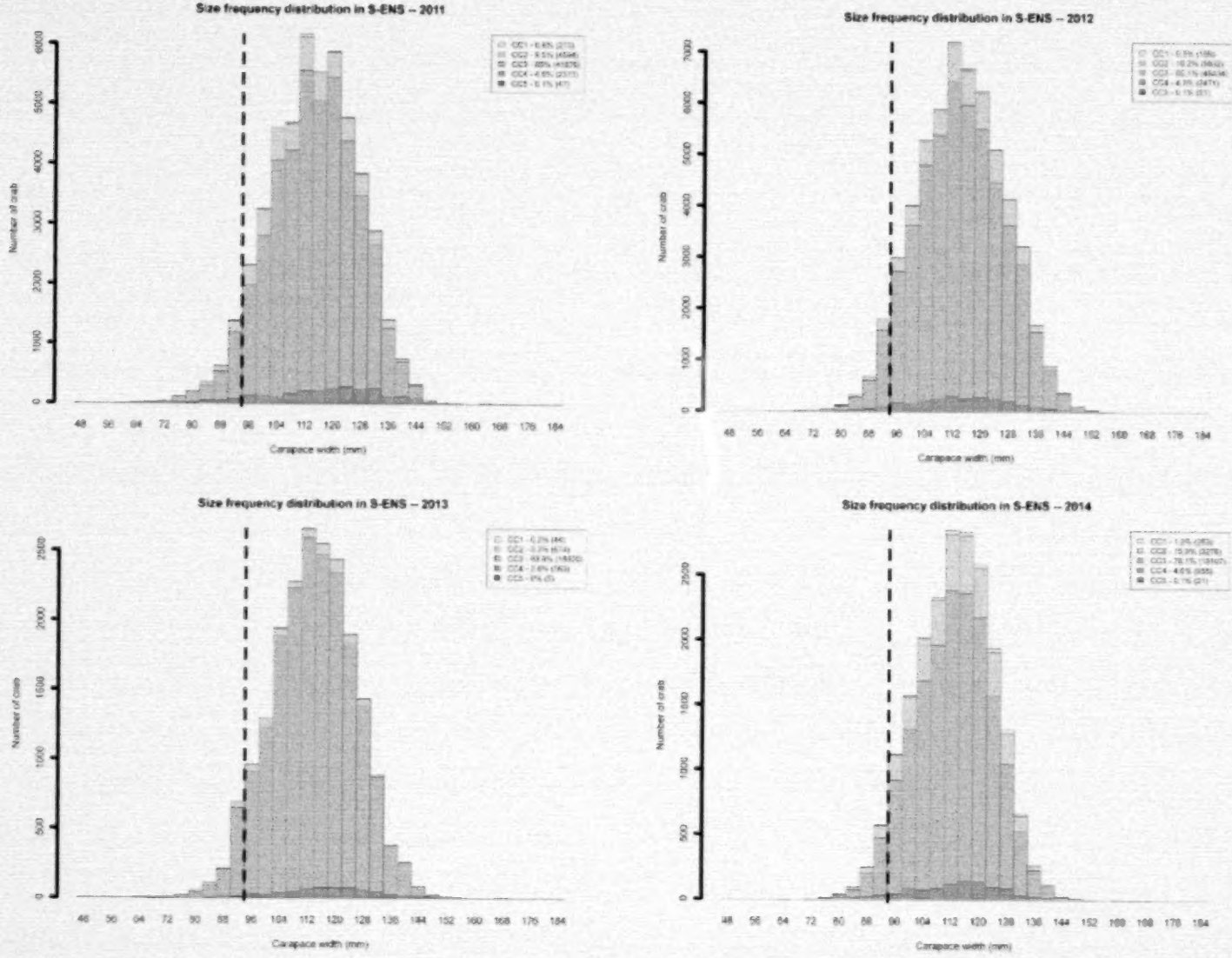

Size frequency distribution in S-ENS -- 2011
Size frequency distribution in S-ENS -- 2012
Size frequency distribution in S-ENS -- 2013
Size frequency distribution in S-ENS -- 2014
Number of crab
Carapace width (mm)

Figure 4b. Size frequency distribution of all at-sea observer monitored snow crab in S-ENS broken down by carapace condition. Vertical lines indicate 95 mm CW.

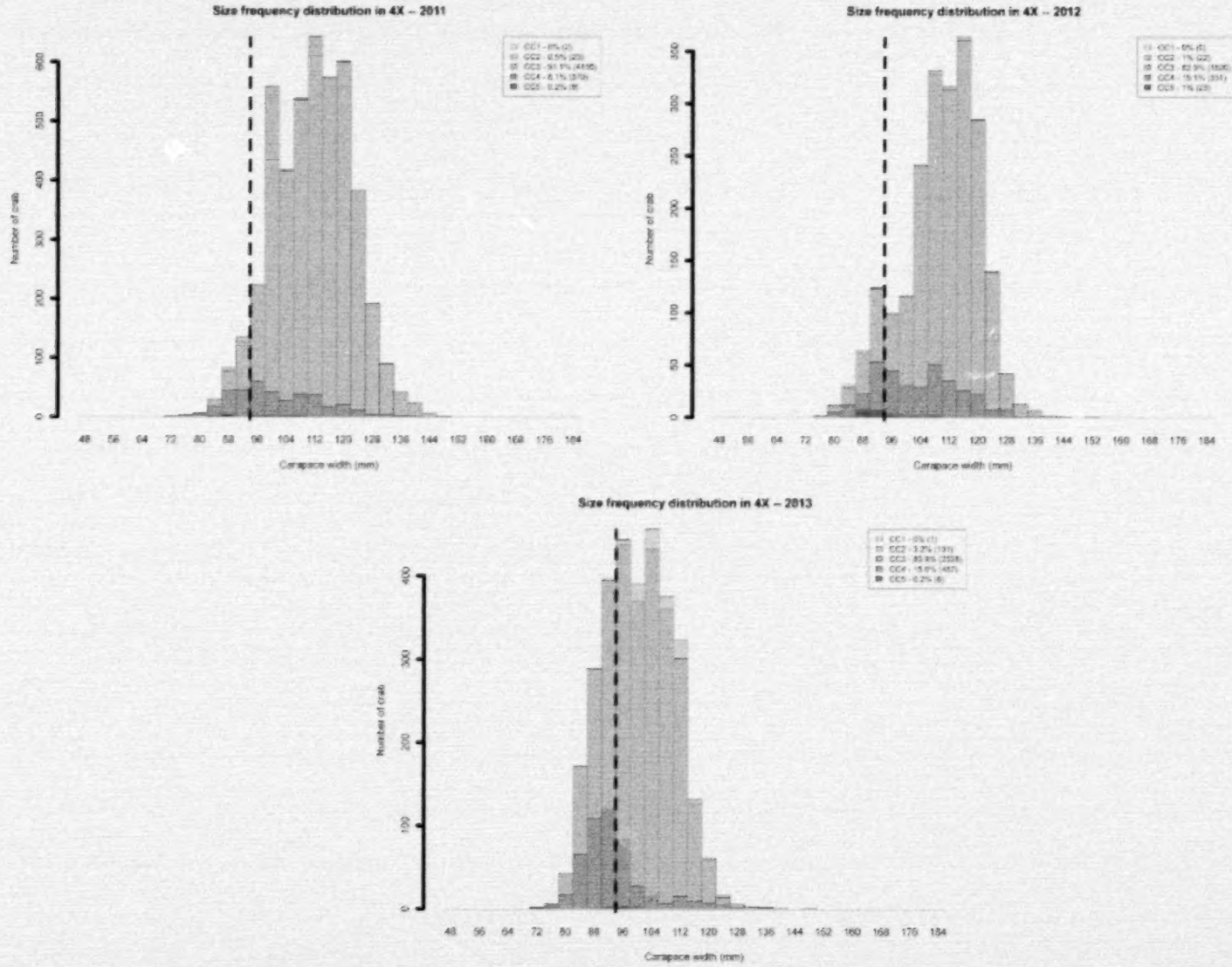

Size frequency distribution in 4X – 2011
Size frequency distribution in 4X – 2012
Size frequency distribution in 4X – 2013
Number of crab
Carapace width (mm)

Figure 4c. Size frequency distribution of all at-sea observer monitored snow crab in 4X broken down by carapace condition. Year refers to the starting year of the season. Vertical lines indicate 95 mm CW.

ASSESSMENT

Stock Trends and Current Status

Fishable Biomass Index

The fishable biomass (Figure 5, Map 3) is defined as that segment of the Snow Crab biomass that is male, mature, larger than 95 mm CW and hard-shelled (with a durometer measure of 68 or greater). The fishable biomass index is estimated from the area expanded trawl survey results.

In N-ENS, the post-fishery fishable biomass index of Snow Crab in 2014 was 2,075 t, relative to 3,451 t in 2013, representing a 40% decrease. This decreasing trend has been observed for the past three years.

In S-ENS, the post-fishery fishable biomass index of Snow Crab in 2014 was estimated to be 40,119 t relative to 46,203 t in 2013, representing a 13% decrease.

In 4X, the pre-fishery fishable biomass was 2,059 t in 2014, relative to 531 t in 2013. The 4X biomass estimate is highly uncertain as only a subset of survey stations were completed in 2014. These estimates should be considered preliminary, pending further analysis of survey and commercial fishing data.

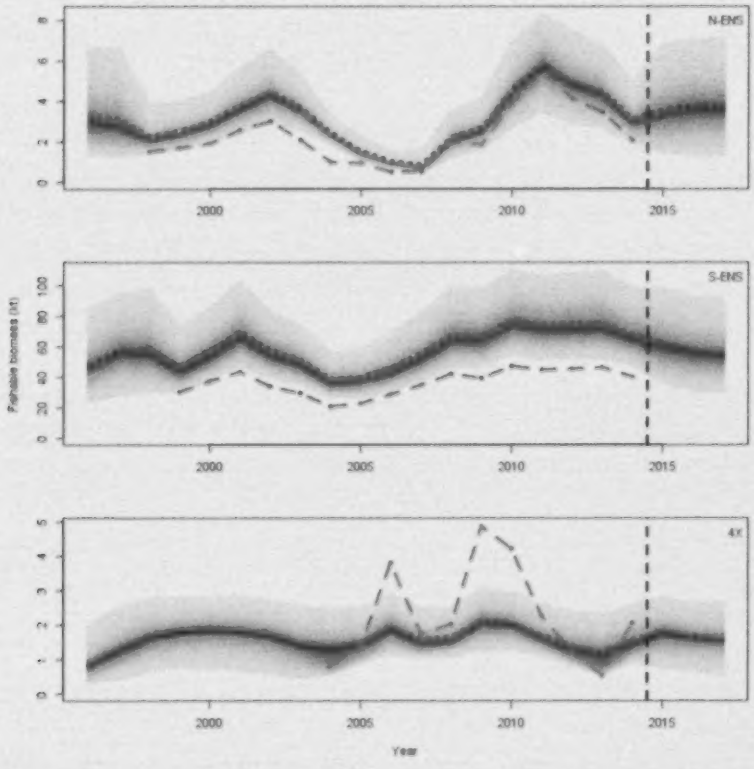


Figure 5. Time series of fishable biomass from the logistic population models. The fishable biomass index is shown in red dashed lines. The posterior mean fishable biomass estimated from the logistic model are shown in blue stippled lines. The density distribution of posterior fishable biomass estimates are presented (gray) with the darkest area being medians and the 95% Credible Intervals (CI). A three year projection assuming a constant exploitation strategy of 20% is also provided.

Recruitment

The index of recruitment into the fishable biomass was obtained from the research survey of mature males with CC1 and CC2 and durometer reading < 68, and CW > 95 mm. Determination of recruitment levels is confounded by terminal molt and the timing offset of moulting (spring) and the survey (fall). Since the onset of the standardized Snow Crab survey in 2004, recruitment (by this measure) remains at relatively low or variable levels in S-ENS and N-ENS, respectively. Based on size-frequency histograms of the male Snow Crab population, very limited internal recruitment to the fishery is expected in N-ENS and 4X (Figure 6). S-ENS internal recruitment is expected to remain at moderate levels. Migration of crab from outside a given area can serve as recruitment to its fishery though is unreliable based on its episodic nature.

In terms of size structure (Figure 6) in S-ENS, the presence of small immature male Snow Crab spanning almost all size ranges (20-95 mm CW) observed by the survey also suggests that recruitment to the fishery is probable for the next four to five years and beyond. In N-ENS, the distribution of male sizes crab appears very similar to that of 2013, though with fewer large mature animals. There remains a persistent gap between 60 and 95 mm CW which will likely result in continued depressed recruitment for the next several years without a migration of crab from adjacent crab fishing areas.

Area 4X shows minimal potential for internal recruitment to the fishery for the foreseeable future, based on size frequency distributions from the trawl survey. Movement is likely an important source of crab in this area and a lack of any commercial fishing effort in the western portion of CFA 24 hold potential benefits for 4X. As always, erratic temperature fields in 4X create strong uncertainties for the future.

Reproduction

Mature female Snow Crab abundance has continued to decline in N-ENS and S- ENS and assumed associated egg production continues to decline after reaching highs in 2007/2008 (Figure 7). Isolated concentrations of mature females exist in S-ENS and 4X with a more diffuse distribution around the CFA 23 / 24 management line and along the southwest coast of Nova Scotia (Map 4). Sex ratios (proportion female) continue to be male-dominated in N-ENS (though slightly higher than 2013), are stabilizing at low levels in S-ENS and declined from more moderate levels in 4X (Figure 7). There was a strong pulse of immature crab observed in the 2014 survey in all areas, which may provide increased production in the future. Newly mature female crab are expected in the next 1-3 years in N-ENS and S-ENS which should increase local egg production (Figure 8). In 4X, there is more uncertainty surrounding short term expectations of egg production.

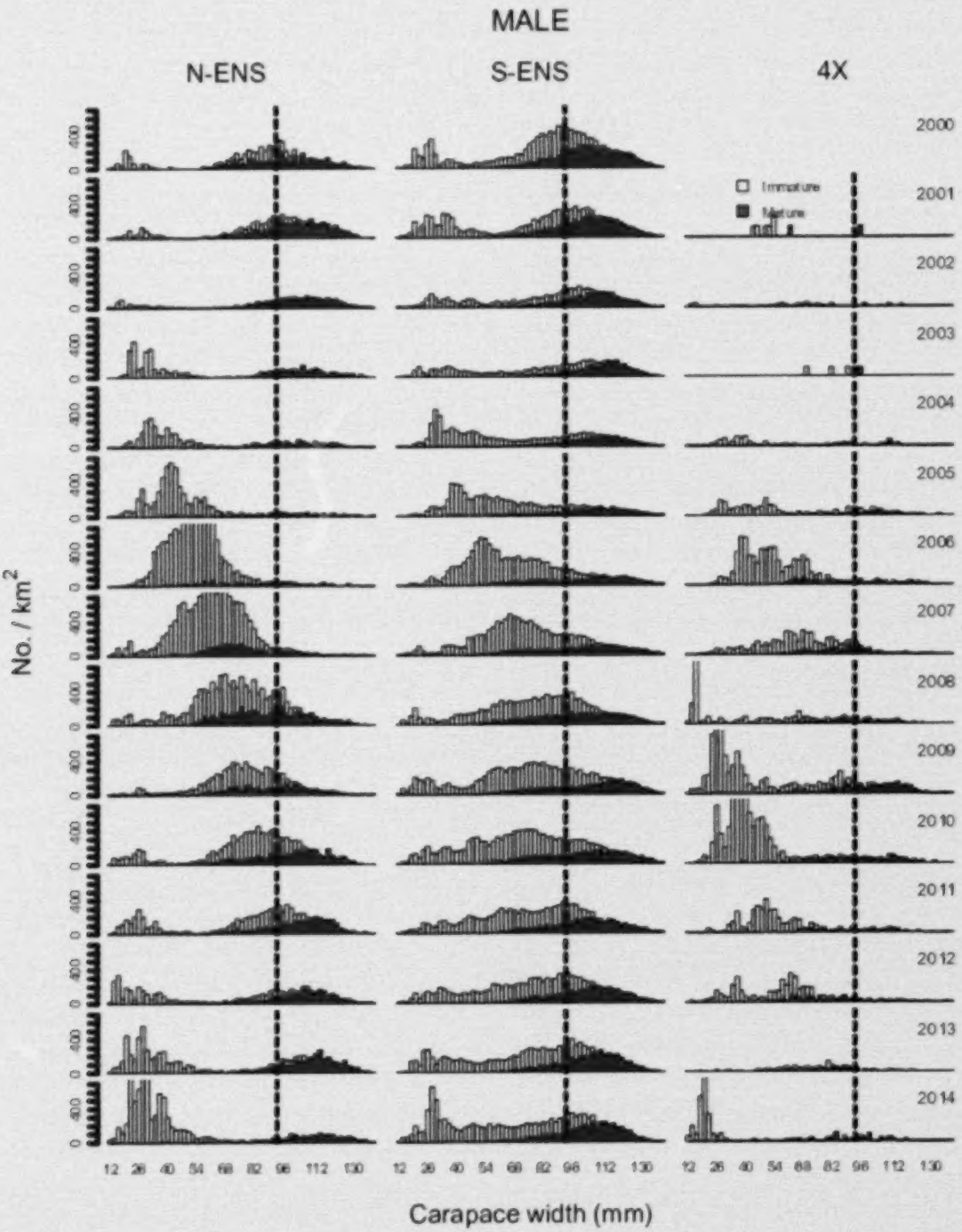


Figure 6. Size-frequency histograms of carapace width of male Snow Crabs. Note the relatively uniform distribution of adolescent crab across all size classes in S-ENS as compared to other areas and previous patterns in S-ENS. Note that for S-ENS and 4X (but not N-ENS) the spatial extent of the surveys have changed over time, making a direct comparison of numerical density inappropriate. This figure provides information about the relative numbers within a given year. The vertical line represents the legal size (95 mm).

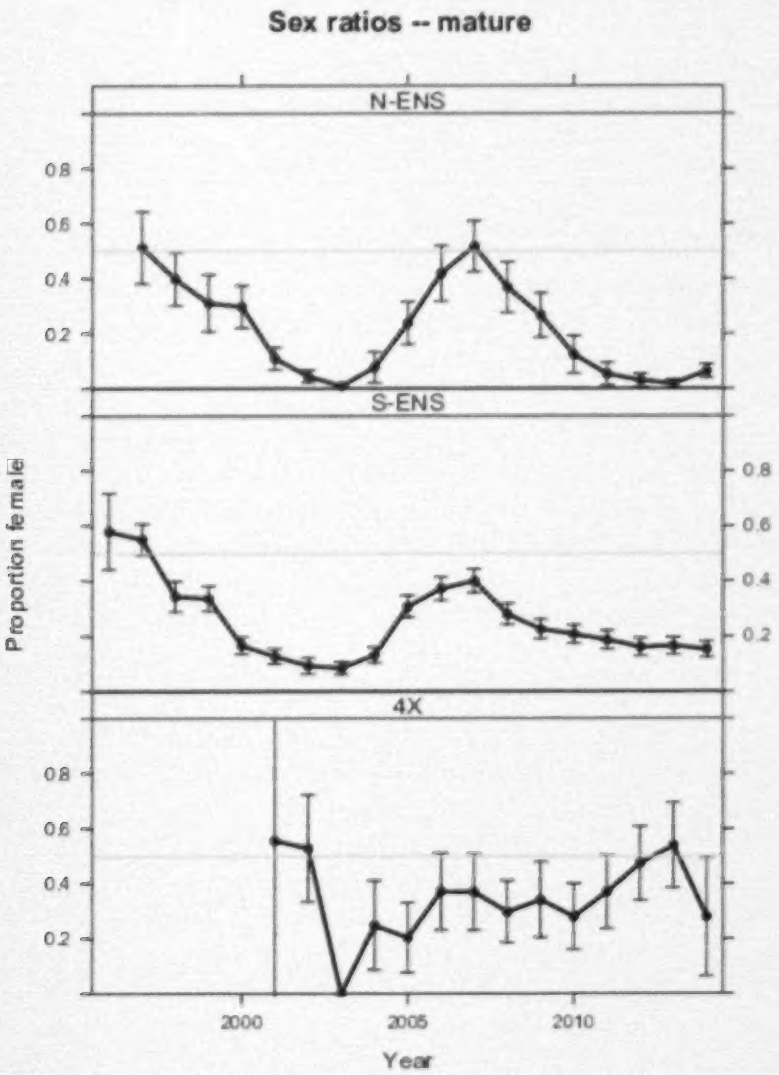


Figure 7. Sex ratios (proportion female) of mature Snow Crab. Since 2000, most of the Scotian Shelf was uniformly male dominated.

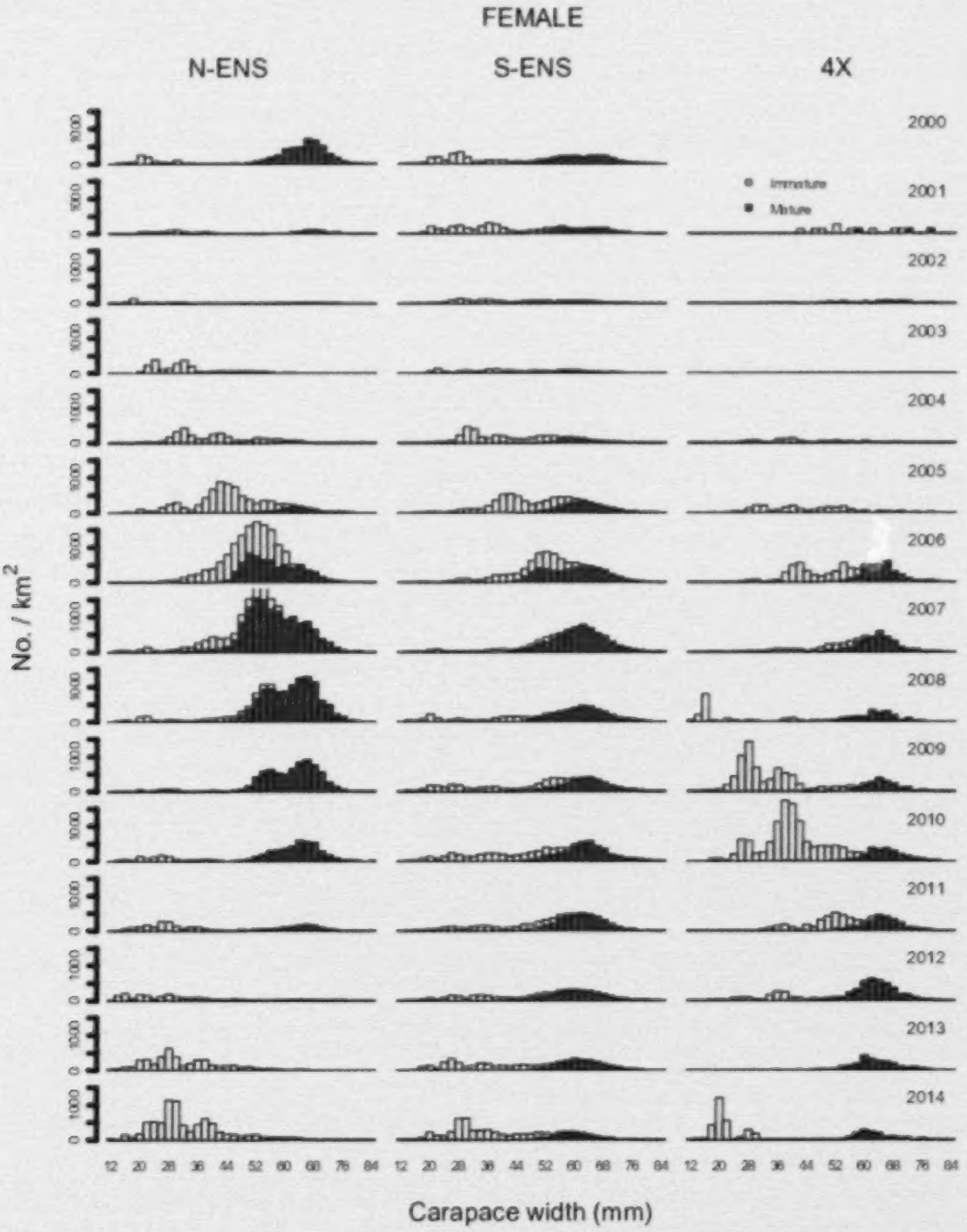


Figure 8. Size-frequency histograms of carapace width of female Snow Crabs. Note that for S-ENS and 4X (but not N-ENS) the spatial extent of the surveys have changed over time, making a direct comparison of numerical density inappropriate. This figure provides information about the relative numbers within a given year.

Fishing Mortality

The abundance estimates of old male crab (CC5) has been stable in the long-term record and below the detection limit on the Scotian Shelf. Their low representation in the survey data and the fishery-observed data may be indicative of high mortality rates of the fishable biomass (fishery-based and/or natural).

In N-ENS, Fishing Mortality (*F*) has been estimated to have been in the range of 0.1 to 0.9, peaking in 2004 (Figure 9). In 2014, fishing mortality is estimated to have been above 0.30 and has been increasing over the last several years. A reduction in fishing mortality in 2008 was implemented to reduce soft shell handling.

Estimated fishing mortality for S-ENS has historically ranged from 0.05 to 0.25, peaking in 2003/2004 (Figure 9). In 2014, fishing mortality was estimated to have been 0.18. Localized exploitation rates are likely higher, as not all areas where biomass estimates are provided are fished (e.g., continental slope areas and western, inshore areas of CFA 24).

In 4X, estimated fishing mortality has historically ranged from 0.2 to > 0.4, peaking in 2005 and 2011/2012 (Figure 9). In 2013/2014, estimated fishing mortality was 0.08. Realized exploitation rates are likely to be higher, since the computed exploitation rates incorporate biomass from throughout the 4X area and not just the fishery grounds.

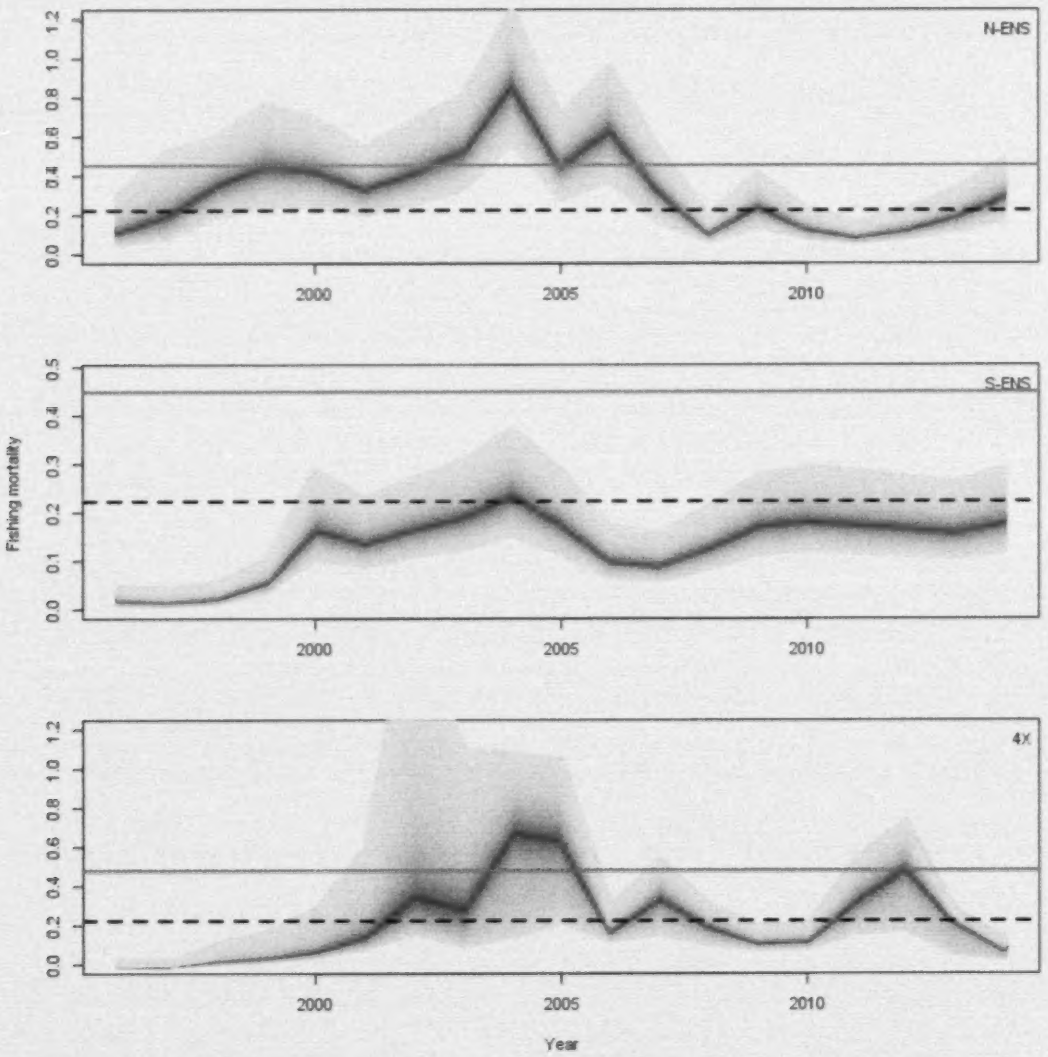


Figure 9. Time-series of fishing mortality from the logistic population models for N-ENS, S-ENS and 4X, respectively. Posterior density distributions are presented in gray, with the darkest line being the median with 95% CI. The red line is the estimated F_{MSY} (F at Maxium Sustainable Yield) and the dark-dashed line is the 20% harvest rate.

Ecosystem Considerations

A multivariate summary of key environmental (climatic), social, economic and fishery-related indicators (Figure 10) suggests that a suite of coherent changes have occurred on the Scotian Shelf since the early 1990s. The first axis of variation accounted for 21.9% of the total variation in the data (Figure 11), and was dominated by the influence of declines in mean body size of organisms in the groundfish surveys; socio-economic indicators of ocean use by humans and associated changes in their relative abundance: landings and landed values of groundfish (declining), invertebrates (increasing), declines in sharks and large demersals and landings of pelagic fish, and oil and gas exploration and development (increasing). Nova Scotia Gross Domestic Product (GDP) and population size were also influential factors that have been increasing. Further the physiological condition of many groups of fish have been

declining as has been the number of fish harvesters in Nova Scotia. The temporal differences along this axis of variation indicates that coherent systemic changes of socio-economic and ecological indicators occurred in the early 1990s, with some return to historical states evident (Figure 11).

Importantly, temperature-related changes were generally orthogonal (independent) to the above axis of variation (not shown). This second (orthogonal) axis of variation, accounting for 10% of the total variation, was strongly associated with the cold intermediate layer temperature and volume, bottom temperatures and variability in bottom temperatures, bottom oxygen concentrations and sea ice coverage.

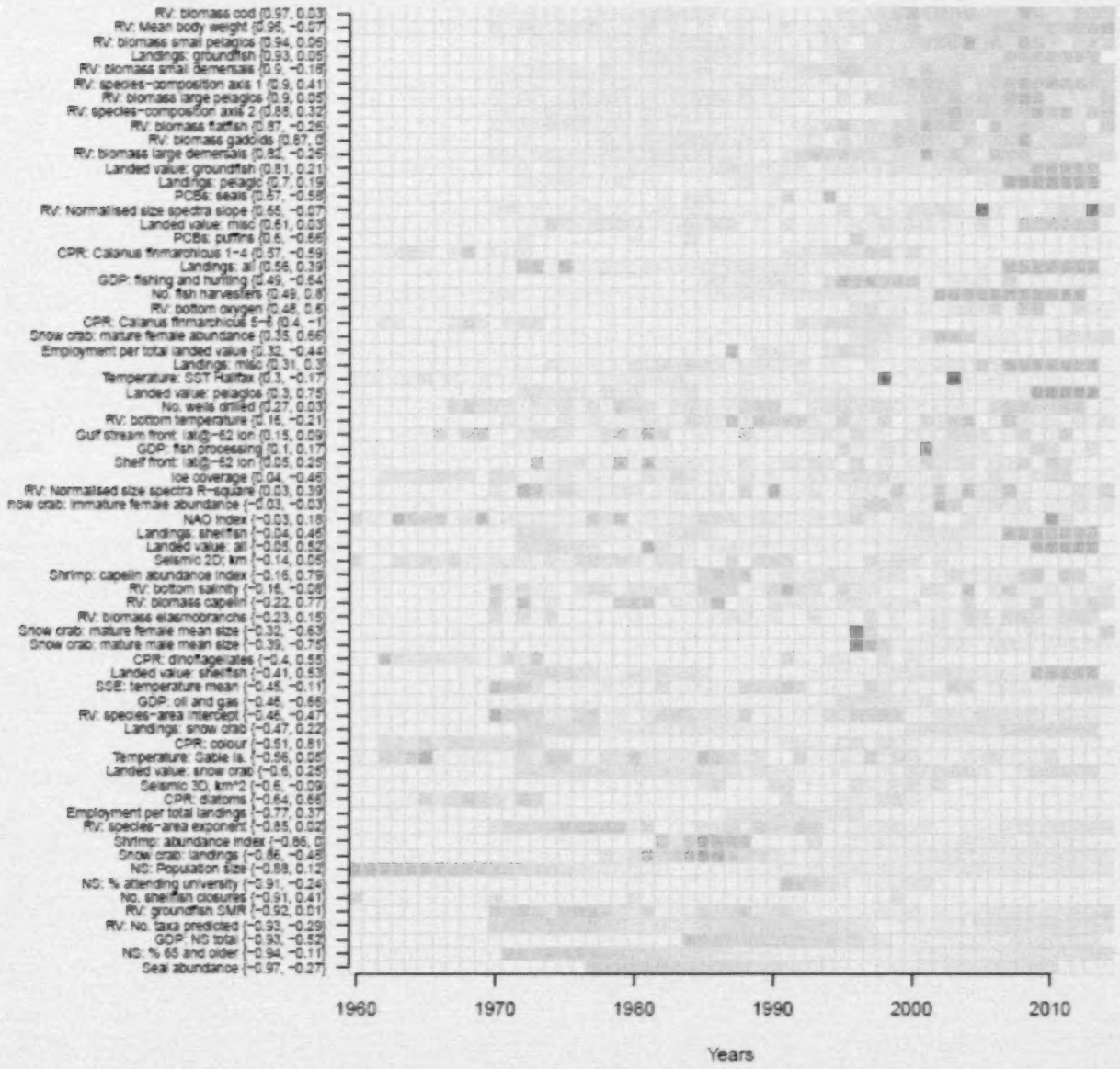

RV: biomass cod (0.97, 0.03)
RV: Mean body weight (0.96, −0.07)
RV: biomass small pelagics (0.94, 0.05)
Landings: groundfish (0.93, 0.05)
RV: biomass small demersals (0.9, −0.15)
RV: species−composition axis 1 (0.9, 0.41)
RV: biomass large pelagics (0.9, 0.05)
RV: species−composition axis 2 (0.88, 0.32)
RV: biomass flatfish (0.87, −0.26)
RV: biomass gadoids (0.87, 0
RV: biomass large demersals (0.82, −0.25)
Landed value: groundfish (0.81, 0.21)
Landings: pelagic (0.7, 0.15)
PCB6: seals (0.67, −0.55)
RV: Normalised size spectra slope (0.65, −0.07)
Landed value: misc (0.61, 0.03)
PCBs: puffins (0.6, −0.66)
CPR: Calanus finmarchicus 1−4 (0.57, −0.59)
Landings: all (0.56, 0.39)
GDP: fishing and hunting (0.49, −0.64)
No. fish harvesters (0.49, 0.8
RV: bottom oxygen (0.48, 0.5)
CPR: Calanus finmarchicus 5−6 (0.4, −1)
Snow crab: mature female abundance (0.35, 0.66)
Employment per total landed value (0.32, −0.44)
Landings: misc (0.31, 0.3)
Temperature: SST Halifax (0.3, −0.17)
Landed value: pelagics (0.3, 0.75)
No. wells drilled (0.27, 0.03)
RV: bottom temperature (0.16, −0.21)
Gulf stream front: lat@−62 lon (0.15, 0.09)
GDP: fish processing (0.1, 0.17)
Shelf front: lat@−62 lon (0.05, 0.25)
Ice coverage (0.04, −0.45)
RV: Normalised size spectra R−square (0.03, 0.39)
now crab: immature female abundance (−0.03, −0.03)
NAO index (−0.03, 0.18)
Landings: shellfish (−0.04, 0.46)
Landed value: all (−0.05, 0.52)
Seismic 2D; km (−0.14, 0.05)
Shrimp: capelin abundance index (−0.16, 0.79)
RV: bottom salinity (−0.16, −0.06)
RV: biomass capelin (−0.22, 0.77)
RV: biomass elasmobranchs (−0.23, 0.15)
Snow crab: mature female mean size (−0.32, −0.63)
Snow crab: mature male mean size (−0.39, −0.75)
CPR: dinoflagellates (−0.4, 0.55)
Landed value: shellfish (−0.41, 0.63)
SSE: temperature mean (−0.45, −0.11)
GDP: oil and gas (−0.46, −0.66)
RV: species−area intercept (−0.46, −0.47)
Landings: snow crab (−0.47, 0.22)
CPR: colour (−0.51, 0.81)
Temperature: Sable Is. (−0.56, 0.05)
Landed value: snow crab (−0.6, 0.25)
Seismic 3D; km^2 (−0.6, −0.29)
CPR: diatoms (−0.64, 0.65)
Employment per total landings (−0.77, 0.37)
RV: species−area exponent (−0.85, 0.02)
Shrimp: abundance index (−0.86, 0
Snow crab: landings (−0.86, −0.45)
NS: Population size (−0.88, 0.12)
NS: % attending university (−0.91, −0.24)
No. shellfish closures (−0.91, 0.41)
RV: groundfish SMR (−0.92, 0.01)
RV: No. taxa predicted (−0.93, −0.29)
GDP: NS total (−0.93, −0.52)
NS: % 65 and older (−0.94, −0.11)
Seal abundance (−0.97, −0.27)
1960
1970
1980
1990
2000
2010
Years

Figure 10. Sorted ordination of anomalies of key social, economic and ecological patterns on the Scotian Shelf relevant to Snow Crab. Red indicates below the mean and green indicates above the mean. Original in colour.

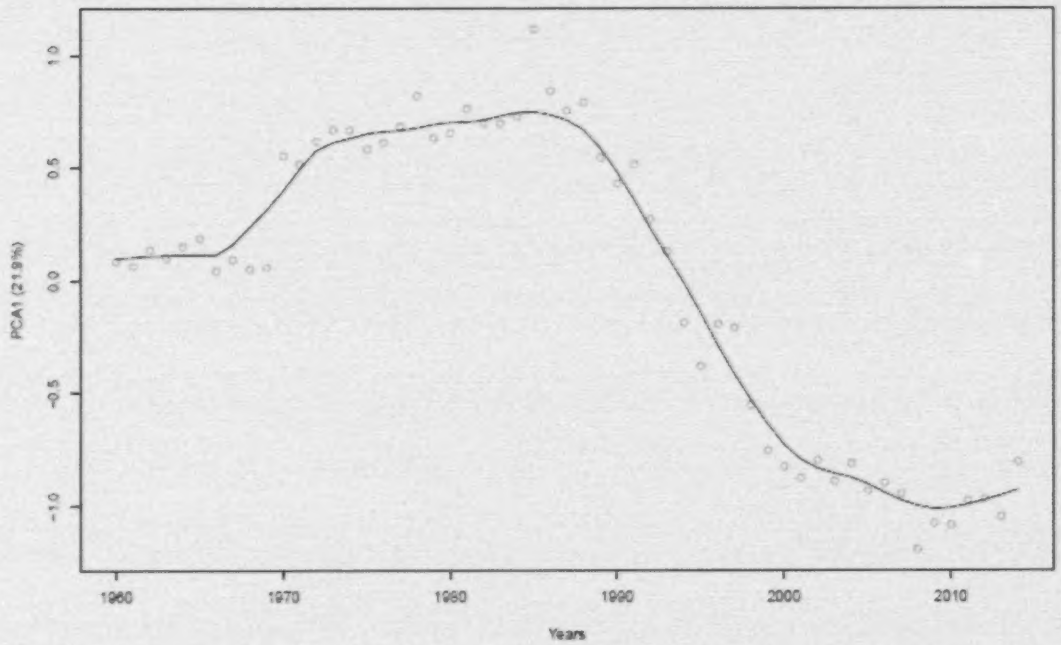


Figure 11. First axis of variation (Principle component axis 1) in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf.

Environmental Variability

Temperature variations within the areas of potential habitat appeared to be robust throughout the historical record (Figure 12). Average bottom temperatures in 2014 were slightly warmer in N-ENS and S-ENS in comparison to 2013, which continues a general warming trend observed since the early-1990s. The bottom temperatures decreased in 4X in each of the past two years after the extreme warm water event of 2012 though still remains just above the long-term mean for the area. Changing temperatures will have an impact on available Snow Crab habitat into the future. The surface area of potential Snow Crab habitat in the SSE was calculated as the arithmetic mean of the potential habitat area estimated in the previous five years (Figure 13).

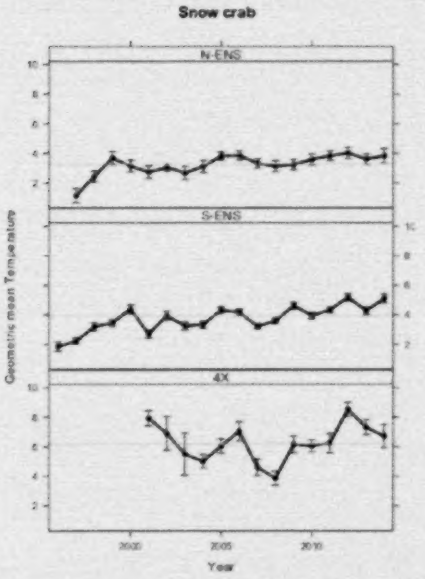


Figure 12. Annual variations in bottom temperature observed during the Snow Crab survey. The horizontal line indicates the long-term median temperature within each subarea. Error bars are 1 standard deviation.

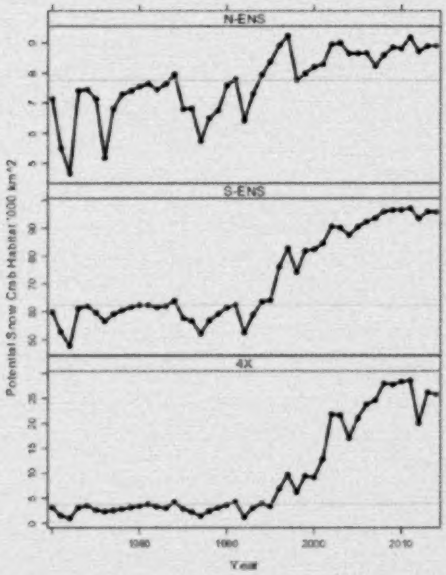


Figure 13. Annual variations in the surface area of potential Snow Crab habitat. The horizontal line indicates the long-term median surface area within each subarea. The estimates for the period from 1998 to the present are based upon Snow Crab surveys while those prior to 1998 are projected using incomplete data (and so less reliable). Within each subarea the 2014 habitat area was estimated using the mean of the past five years.

Bottom-up (Resource Limitation)

Food items such as Northern Shrimp are found in concentrations comparable to the long-term average in most core areas of S-ENS (based on Snow Crab trawl survey; Map 5).

Near the ocean surface, there has been a trend towards increased ocean colour, which is an index of chlorophyll concentrations. Therefore, total primary production may be increasing (in the form of diatoms and dinoflagellates). This is likely enhanced by the reduction in abundance of *Calanus finmarchicus*, an important zooplankton link in the pelagic food web. Whether this elevated primary production reaches the detrital system is not yet known.

Top-down (Predation)

The capacity of predatory groundfish to opportunistically feed upon Snow Crab, in combination with their numerical dominance prior to the 1990s, suggests that they may have been an important regulating factor controlling the recruitment of Snow Crab. The demise of these predatory groundfish in the post-1990 period (Figure 10), and the resultant release from predation upon the immature and soft-shelled crabs, may have been an important determinant of the current rise to dominance of Snow Crab in the SSE. Based on stomach sampling, Atlantic Halibut, Atlantic Wolfish and skate species appear to be the predominant predators of Snow Crab, though it does not appear to represent more than 2.2% of their diet on the Scotian Shelf. Of these species, only Atlantic Halibut biomass indices appear to be increasing in both surveys (Snow Crab and groundfish; figures 14, 15), suggesting that the total number

of Snow Crab consumed may be increasing in relation to this predator and this additional source of mortality should be examined more thoroughly. The status of Thorny, Smooth and Winter skates are uncertain as the two survey trends show somewhat different patterns, which is likely reflective of the differences in trawl efficiency. Increased predation may lower future recruitment to the fishable biomass and affect movement patterns of Snow Crab.

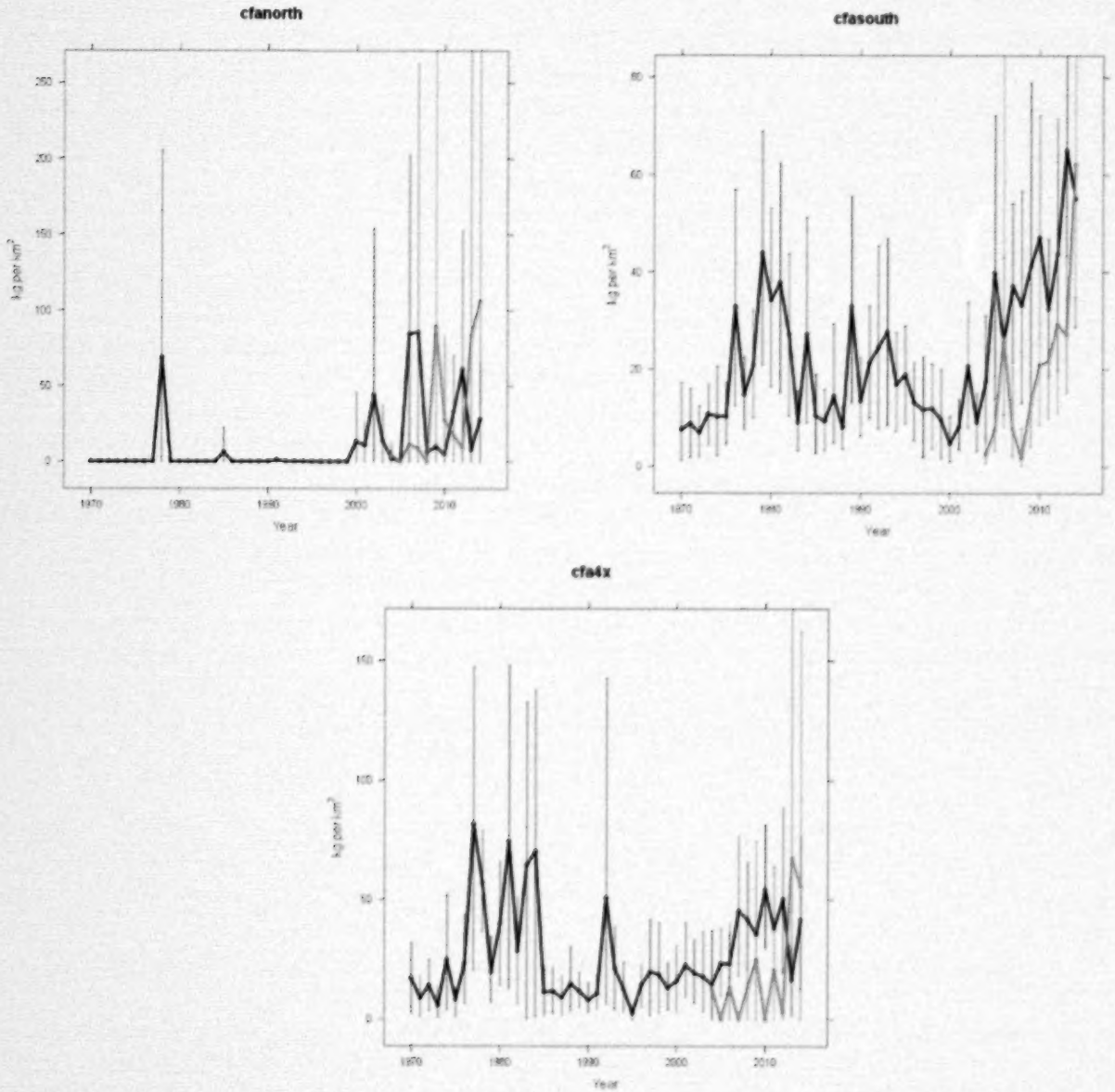


*Figure 14. Trends in biomass for potential **predators** of Snow Crab on the Scotian Shelf: **Atlantic Halibut**. Black line represents trends from DFO's summer research vessel survey where N-ENS is captured by strata 440-442, S-ENS is depicted by strata 443-467 and 4X is depicted by strata 470-483. Red line represents trends from annual Snow Crab survey. In both, verticle lines are 95% confidence intervals estimated by bootstrapping.*

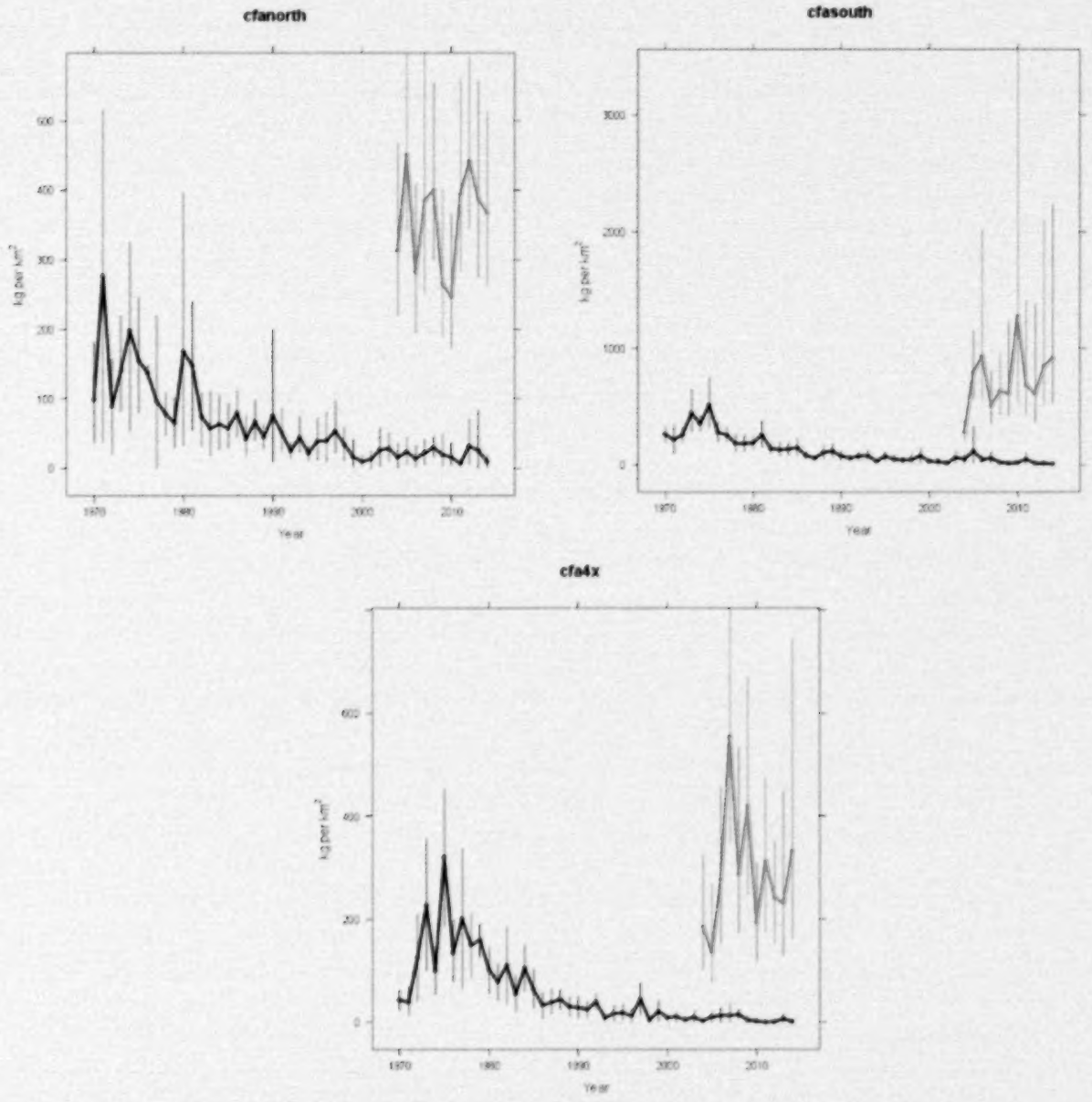


Figure 15. Trends in biomass for potential ***predators*** *of Snow Crab on the Scotian Shelf:* ***Thorny Skate****. Black line represents trends from DFO's summer research vessel survey where N-ENS is captured by strata 440-442, S-ENS is depicted by strata 443-467 and 4X is depicted by strata 470-483. Red line represents trends from annual Snow Crab survey. In both, verticle lines are 95% confidence intervals estimated by bootstrapping.*

Seals are considered by some fishers to be a predator of Snow Crab, and their continued increase in abundance (Figure 10) is a source of concern for some fishers and some scientists. While seals have been observed with Snow Crab in their stomachs, it should also be emphasized that high concentrations of Snow Crab are found in the immediate vicinity of Sable Island, an area where the abundance of Grey Seals is extremely high. The evidence indicating that seals have a negative influence upon the Snow Crab population, therefore, seems to be minimal. In fact, it is quite possible

that seals may be having a positive influence by physically importing food and food waste (organic matter) from other more outlying areas to the immediate vicinity of Sable Island. This would indirectly "feed" the Snow Crab and also protect them from potential predators of crab (in both early pelagic and benthic stages). Seal predation of groundfish would lower potential lateral competition for Snow Crab food resources.

Lateral (Competition)

Large mature males stabilize the Snow Crab population by maintaining and occupying prime crab habitat. Large mature males keep at bay potential competitors such as other crab species or even groundfish, serve as strong mates for the current population pulse of mature females, and are protectors of the smaller females. Their over-exploitation can have numerous negative biological consequences. An important consequence of the extended period of low numbers of females to males (Figure 8) observed in the early-2000s throughout the Scotian Shelf is that poor egg and larval production in the system likely occurred for at least a four to five year period. Similarly poor egg production is likely now occurring. Stabilisation of such strong oscillations in abundance into the future may be possible if reproduction of the currently available females is supported by an adequate population of large males.

The diet of Snow Crab overlap in many ways with that of some groundfish species; thus, the demise of these groundfish groups in the late-1980s and early-1990s would have been doubly beneficial to Snow Crab through the reduction in both predation pressure and resource competition. A negative relationship is not found between snow crab and other Snow Crab survey bycatch species, suggestive of little competitive interactions. The potential competitors, Lesser Toad Crab and Jonah Crab, remain in relatively patchy distributions and, therefore, do not currently appear to pose much threat to the overall health of the Snow Crab stock.

Human Influences

Oil and gas exploration and development has and continues to occur on the Scotian Shelf near to, or upstream of, major Snow Crab fishing grounds and Snow Crab population centers in both N-ENS and S-ENS. Seismic surveys are used by the oil and gas industry to identify areas of petroleum resource potential beneath the seafloor (Breeze and Horsman 2005). The effects of offshore oil and gas seismic exploration on potentially-vulnerable components of the Snow Crab population (e.g. eggs, larvae, and soft-shelled crab), as well as on the long-term biological development and behaviour of this long-lived species, are still not known (DFO 2004; Boudreau et al. 2009; Courtenay et al. 2009). However, anecdotal evidence following seismic exploration that occurred in November 2005 over the Glace Bay Hole and the shallows of the Sydney Bight (i.e. Hunt Oil 2005), where immature and female crab are generally abundant, suggested that seismic may have impacted the Snow Crab population proximal to the exploration program. The Canada-Nova Scotia Offshore Petroleum Board (CNSOPB), the regulator that oversees the petroleum industry that operates in the offshore of Nova Scotia, may issue Call for Bids for offshore exploration in N-ENS and S-ENS in 2016 and 2017, as part of its current three year plan (CNSOPB 2015). Future seismic exploration in offshore areas occupied by Snow Crab may need to evaluate the impacts on the species.

Undersea cables have been identified by fishers as a source of concern although, at present, there is no information available to definitively describe the effects of undersea cables upon Snow Crab. In particular, the Maritime Link subsea electrical transmission project in N-ENS has proposed that two cables be laid on the seafloor and spaced by up to 200 m apart. These cables may create a barrier to normal Snow Crab movement through static magnetic fields, increased temperature, induced electrical fields, or the physical barriers created as a result of trenching activities and substrate disturbance. Changes in predator fields may occur as magnetic fields have been shown to attract certain species (Formicki et al. 2004). Additional tagging efforts continue to be applied in this area by the project

proponent, members of the fishing industry, and DFO to better understand Snow Crab movement prior to the proposed installation of the cables.

St Ann's Bank has been identified as an Area of Interest (AOI) for designation as a Marine Protected Area (MPA). The complex consequences of this designation are still to be determined. The presence of a refuge from fishing activities is positive as it could serve as a fallow area. However, if the reserve is disproportionately beneficial to other organisms, be they predators or prey of Snow Crab, the effects upon Snow Crab could be mixed. The long-term effects of the AOI/MPA cannot be determined at this point.

Bycatch / Incidental Catch

Bycatch levels in the SSE Snow Crab fishery have been extremely low in the long-term record. Estimates of bycatch in this fishery are extrapolated from at-sea observer estimates. In ENS, estimates of bycatch were 0.01% of Snow Crab landings (5.3% and 4.2% observer coverage in N-ENS and S-ENS, respectively). 4X shows higher (relative to ENS) bycatch rates at 2.2 % of Snow Crab landings (12.8% observer coverage in 4X). The majority of bycatch for all areas is composed of other invertebrate species (e.g., Northern Stone Crab and American Lobster) for which higher survival rates can be expected after being released as compared to fin fish discards. In previous years, at-sea observers reported two Leatherback Sea Turtles as having been entangled in buoy lines, both released alive though bleeding. A Humpback Whale was entangled in buoy lines in 2012 which was released with little or no harm to the animal.

Bycatch of Snow Crab from other fisheries is still not quantified. Trawls can increase mortality, especially upon the soft-shelled phases of Snow Crab, though the lack of trawl fisheries (other than shrimp trawling) in the majority of Snow Crab habitat on the Scotian Shelf limits this potential damage. Bottom damage from the placement of Snow Crab traps is thought to be very minimal.

Sources of Uncertainty

Several sources of uncertainty exist with this fishery and productivity of Snow Crab. These sources include, environmental uncertainty associated with rapid climate change,uncertainty in the relative abundance of predators and the uncertainty in external human influences (i.e. oil and gas exploration, electrical transmission cables). To remain adaptive in the face of these significant uncertainties, industry and management must continue to be mindful and vigilant in maintaining a small enough fishery and more generally a smaller human footprint, such that these larger ecosystem uncertainties will not further be exacerbated by our activities. Anecdotal reports from the Snow Crab industry suggest that unreported and misreported catch is occurring, particularly in S-ENS. Such activities increase the uncertainty in the stock assessment results and hinder the steps made toward applying a precautionary approach to the management of this resource.

Concerns are continually raised by the fishing industry regarding the impact of seismic activity on local Snow Crab and the potential source of uncertainty it raises for future productivity and the impacts on the stock assessment results.

Potential uncertainty exists in N-ENS regarding migration into the area that is not detected during trawl surveys, which may affect the biomass available during the fishery.

In all areas, fishable biomass estimates were more uncertain in 2014 compared to previous years due to changes in survey timing, survey duration and vessel.

CONCLUSIONS AND ADVICE

Precautionary Approach

Many existing measures and fishing practices in the Scotian Shelf Snow Crab fishery are inherently "precautionary" and should be reiterated:

- The prompt and careful return of immature (small- claw, non-terminally moulted) crab to the water is an important conservation measure that will enhance the mid-term (2-3 year) sustainability of this fishery. This is a measure that needs to continue.
- No removal of female crab. Reproductive potential of spawning stock biomass is not disrupted. Most removals of males occur after mating and sub-legal mature crab (able to reproduce) are never removed.
- Conservative exploitation strategies have generally been the norm, especially in recent years.
- Refugia from directed fishing pressures exist in the Gully MPA, along the continental slope, and much of the western inshore portion of CFA 24.
- Immature and soft-shelled (newly-moulted, easily damaged) crab are not harvested and handling mortality is minimized via area closures, low economic value, education, and at-sea observer monitoring of soft-shell incidence has helped to maximize the potential yield per animal to the biomass.

Harvest Control Rules (HCR) have been developed which link the biomass reference points to the exploitation reference points (Figure 16). In the Cautious and Healthy zones, actual target harvest rates are shaped by a suite of secondary indicators that provide more complete information on the entire stock's health. These secondary indicators are used to inform management decisions under the HCR linking the stock references to harvest strategies. Secondary indicators include expected recruitment, spawning stock biomass, size and age structure of various stock components, sex ratios, environmental variables, fishery performance and others. If a stock is determined to be in the Critical zone, all fishing activities cease with the belief that this will allow the stock to rebuild.

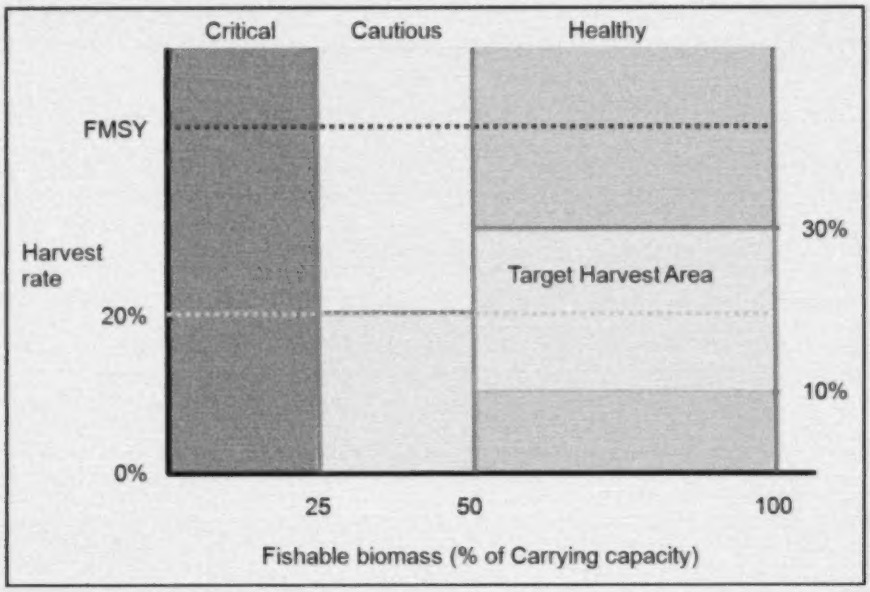


Figure 16. Harvest control rules for the SSE Snow Crab fishery.

The operational reference points associated with the 4VWX Snow Crab fishery are as follows:

* **Lower Stock Reference (LSR)**: 25% of carrying capacity

* **Upper Stock Reference (USR)**: 50% of carrying capacity.

* **Removal Reference (RR)**: not to exceed F_{MSY} (where F is the fishing mortality of the legal sized mature male population and MSY is the theoretical Maximum Sustainable Yield)

* **Target Removal Reference (TRR)**: 20% of the fishable biomass (F=0.22). Secondary, contextual indicators are used to alter harvest rates between 10 and 30% of fishable biomass (FB; F=0.11 to F=0.36).

The Harvest Control Rules are, therefore, as follows:

- FB > USR : target exploitation rate of 10% - 30% be utilized, based upon contextual information provided by secondary indicators
- LSR < FB < USR : target exploitation rate of 0% - 20%, based upon contextual information provided by secondary indicators
- FB < LSR : fishery closure until recovery (at a minimum, until FB > LSR)

From the logistic model output the current estimates of "carrying capacity" for the fishable biomass of snow crab is estimated to be {and 95% CI}:

- N-ENS: 5.72 {4.13, 8.45} kt
- S-ENS: 76.3 {55.1, 109} kt
- 4X: 2.11 {1.59, 2.86} kt

The estimates of F_{MSY} {and 95% CI} were:

- N-ENS: 0.453 {0.36, 0.55}
- S-ENS: 0.453 {0.35, 0.55}
- 4X: 0.478 {0.38, 0.58}

Estimates for 4X should be considered highly uncertain, due to the brevity of their data series and uncertain nature of their error distributions.

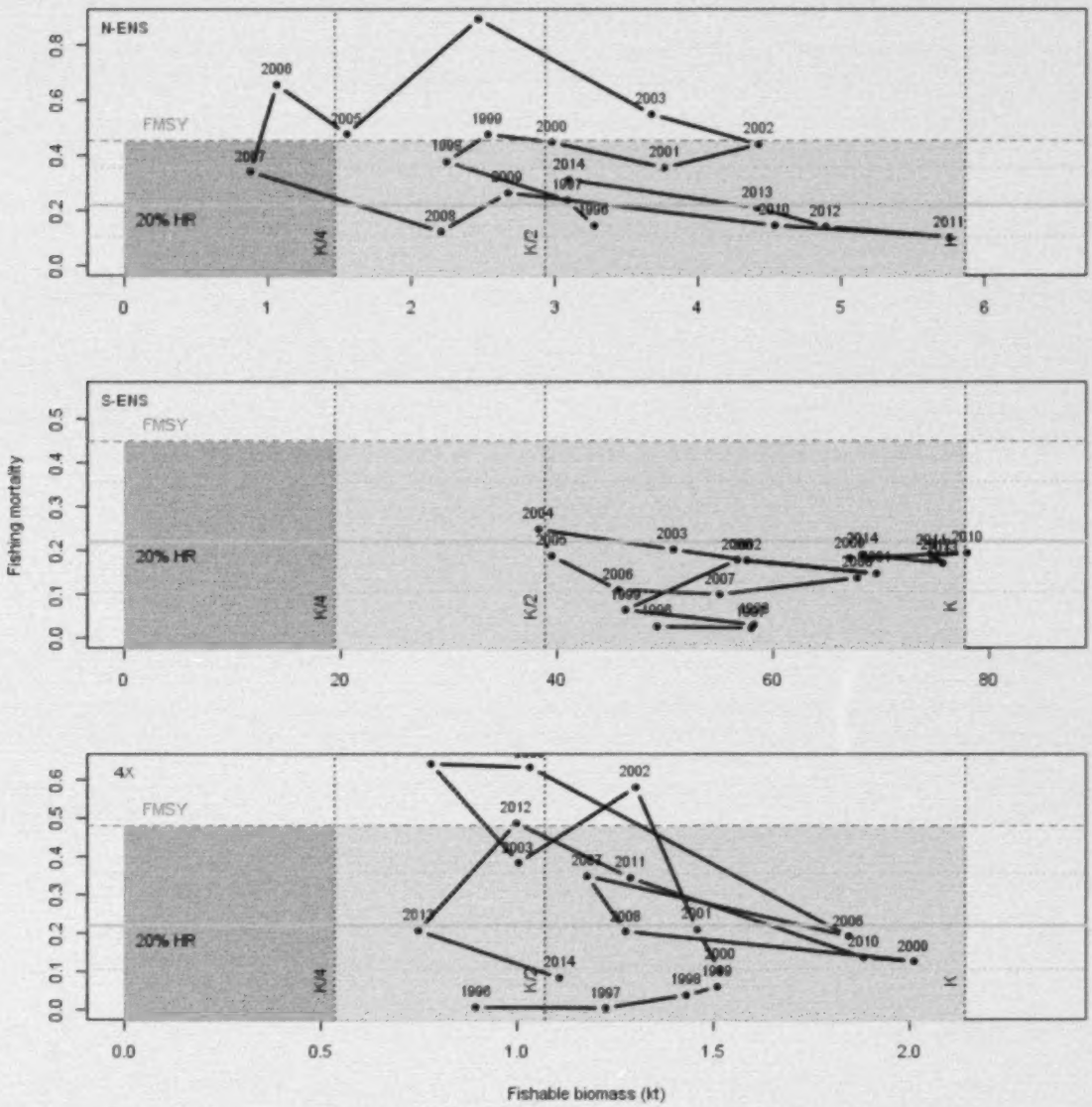


Figure 17. Time series of fishing mortality and fishable biomass for N-ENS (top), S-ENS (middle) and 4X (bottom) as obtained from the logistic population models. Red arrow indicates current (2014) year.

Conclusions

Catches of soft shell crab are a potential issue in N-ENS and S-ENS (but not 4X due to their offset fishing season), depending on the balance of spring or summer fishing activities. Timely responses from industry to avoid fishing in areas showing potential or actual high incidence of soft crab must continue if unnecessary mortality of future recruits is to be averted. An earlier season in N-ENS and S-ENS appeared to significantly reduce soft shell handling and should continue whenever possible in future years.

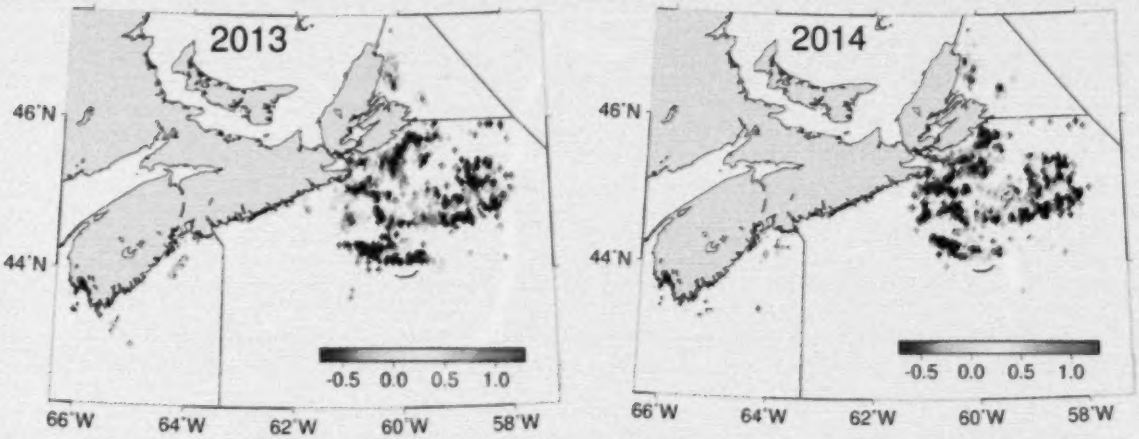
A reference points-based Precautionary Approach (PA) has been implemented in this fishery. The Limit Reference Point (LRP) is 25% of carrying capacity and the Upper Stock Reference (USR) is 50% of

carrying capacity. The Target Removal Reference is 20% of the fishable biomass in each area and the Removal Reference is not to exceed F_{MSY}. Various secondary (population and ecosystem) indicators are taken into consideration for management decisions (Figure 16).

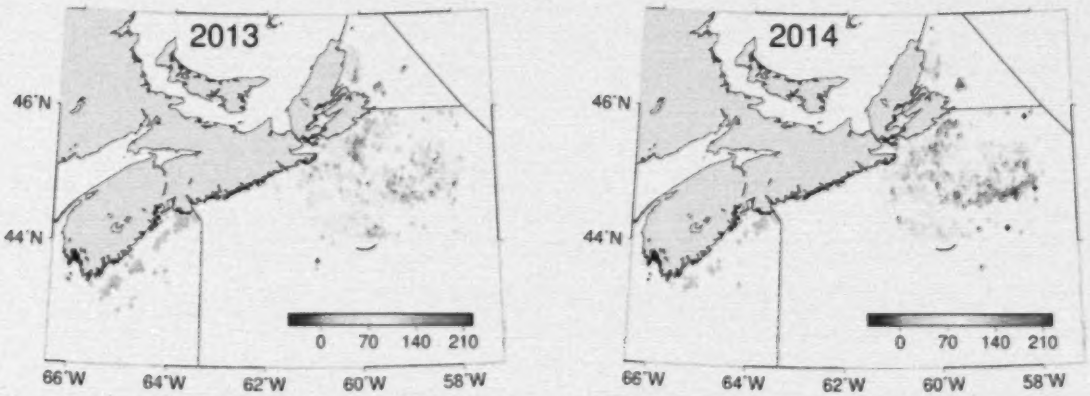
In N-ENS, high exploitation rates and limited recruitment caused by handling mortality of soft-shelled crab in the past pushed the N-ENS fishable biomass (FB) to historic lows. In N-ENS, fishable biomass has declined over the past three years, although the stock remains in the "healthy" zone (FB > USR; Figure 17), it is getting close to the "cautious" zone. The mature component of the stock in this area does appear to be ageing as there was a significant component of CC4 crab observed during the fishing season. However, there were some CC2 crab observed during the fishing season. These crab were not evident in 2013 or previous length frequency data or in the 2014 survey, and, thus, may constitute an migrant event from neighbouring areas. There remains a gap in the length frequency histogram, suggesting limited local recruitment in the medium to long-term. Based on the biomass trends obtained during the survey a decreased TAC is recommended.

The long-term, PA adopted by the S-ENS fishers since 2004 appears to be creating increased stability in commercial biomass levels. This stability is an important consideration, given the continued uncertainty in world markets and the more volatile state of other Atlantic Canadian Snow Crab populations. The S-ENS population is considered to be in the "healthy" zone (FB > USR; Figure 17). Despite the slight decrease in fishable biomass it continues to be high relative to historic levels and with recruitment expected for at least the next three to four years, there remains scope for flexibility. A status-quo to marginal decrease in TAC is recommended.

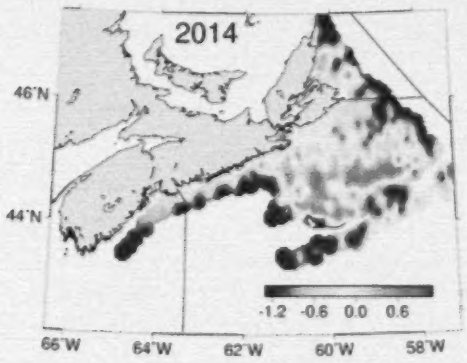
As Area 4X is the southern-most area of Snow Crab distribution, existing in more "marginal" environments relative to the "prime" areas of S- and N-ENS, an explicitly PA towards this fishery is essential. Further, the lower recruitment into the fishable biomass and the large inter-annual temperature variations (especially in 2012) increases the uncertainty associated with this area. Indeed the speculated increases in mortality associated with the warm temperature event in 2012, most likely occurred as most measures of Snow Crab productivity decreased in the area. The 2012/2013 fishery landed approximately 45% of TAC, which resulted in a decrease in TAC for 2013/2014 to 80 t. In the past, S-ENS has been assumed to provide a buffer for 4X via immigration as evidenced by a large portion of 4X's commercial biomass being proximal to the S-ENS line. At present, fishable biomass has moved from the "cautious" zone (LSR < FB < USR) into the "healthy" zone (USR < FB, Figure 17), however there is considerable uncertainty in this biomass estimate as the westernmost portion of the survey stations in 4X were not completed. In addition, recruitment into next season is uncertain leading to the recommendation of a continued conservative harvest strategy pending further analysis prior to the 2015-2016 season.



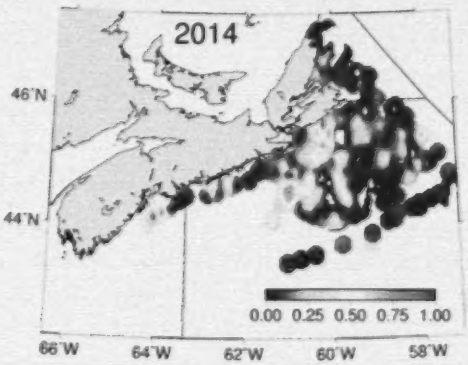
Map 1. Snow crab landings (log10(kg/1mingrid) from fisheries logbook data for 2013 and 2014. Note the increase in landings inshore in S-ENS. For 4X, year refers to the starting year.Original figure in colour.



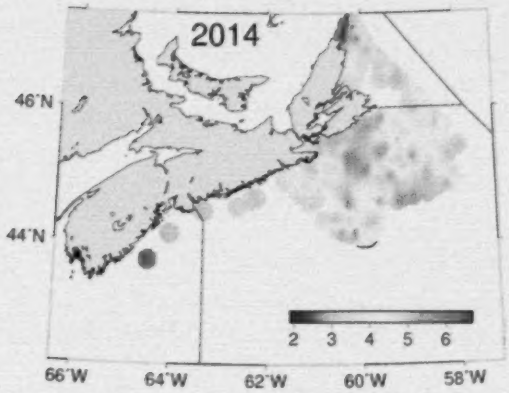
Map 2. Average catch rates (kg/trap haul) of Snow Crab on the Scotian Shelf in 2013 and 2014. Original figure in colour.



Map 3. Fishable biomass from the 2014 Snow Crab survey. Log 10 scale. Original figure in colour.



Map 4. Proportion of females in the mature population. Note the heterogeneous distribution of sexes in all areas. Original figure in colour.



Map 5. Number of Northern shrimp, a food item of Snow Crab. Log 10 scale. Original figure in colour.

SOURCES OF INFORMATION

This Science Advisory Report is from the February 24, 2015, Assessment of Nova Scotia (4VWX) Snow Crab. Additional publications from this process will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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